APPLICATION OF FIBRE OPTIC LINKS BETWEEN SUBSTATIONS IN QATAR AND OMAN ELECTRIC POWER COMMUNICATION SYSTEM

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Abstract: *This paper deals with technical and economic aspects of application of fibre optic links between substations and their contribution to the modernization of electric power systems. A modern electric power communication system should meet the requirements for transmission of different kinds of signals, such as data transmission for power control systems and energy trading information systems, distance and differential protection signal transmission via overhead lines and power cables, speech transmission for despatching control systems, telecommunication management network signal transmission, etc. For the first, advantages and disadvantages of application of different fibre optic cable solutions are summarized. Then, technical and economic parameters important in process of planning of these systems are considered. Finally, as illustration, several examples are given, based on experience in implementation and designing of these systems in Qatar and Oman, including some measuring results and environmental impact aspect.*

Key Words: *Power Communication System, Fiber Optic Cable, Optical Ground Wire Cable (OPGW), Optical attenuation, Splice attenuation*

1. INTRODUCTION

Modernization of electric power systems for generation, transmission and distribution of electric energy nowadays is mostly done by the expansion and modification of the existing systems and introduction of fully new technological solutions with the aim to transmit energy from the source to a user in a more rational and efficient way. Telecommunication systems play an important role in these systems because of the advanced technologies developed in the last two decades, especially in the area of fibre optic technology application

A modern electric power communication system should meet the requirements for transmission of different kinds of signals, such as:

- Data transmission for power control system (PCS);
- Data transmission for energy trading information systems (ETIS);
- Distance and differential protection signal transmission via overhead (O/H) lines and power cables;

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- Speech transmission for dispatching control systems, and
- Telecommunication management network (TMN) signal transmission.

In addition, there is often a need to transmit signals along two independent and physically separated paths to ensure required reliability and availability of system.

The ever increasing telecommunication needs have formed a "bottle-neck" in existing systems (such as Power Link Carrier - PLC, symmetric wire cables and analogue radio links) due to rather small possibilities of their expansion and more severe requirements for the quantity and speed as well as quality and reliability of transmission. That is why the application of advanced telecommunication technologies is indispensable.

This paper deals with the areas in which, in our opinion, advanced telecommunication technologies can give an important contribution to the modernization of an electric power communication system. The emphasis is given on fibre optic cable systems between substations, which are successfully applied nowadays.

Application of fiber optic cables in electric power communication systems has the following advantages in comparison with wire cables:

- Complete potential separation between the terminal equipment;
- Total immunity of the communication path to electromagnetic interference;
- Application of digital communication technology, and
- Large bandwidth (transmission capacity) for transmission of different kinds of signals.

Due to non-metallic construction of optical cables, earth potential problems under fault conditions are eliminated.

The process of planning of these systems is usually based on technical and economic analysis of different options, their advantages and disadvantages and the choice of optimal solution that will be applied in this particular case. That is why different options are summarized in the paper and some technical and economic parameters important in process of planning of these systems are considered. These considerations are based on experience in design and implementation of different systems, which are reviewed in briefly.

2. FIBER OPTIC (FO) CABLE OPTIONS

The following groups of solutions in application of optical technology are possible:

- Underground cables (as pilot cables along power cables and communication cables laid on independent way leaves), and
- Aerial cables (as self-supporting cables, suspended on towers of the existing overhead power lines, under the conductors, wrap on cables, wrapped on the ground wires of the existing overhead power lines, lashed cables, fixed to the ground wires of the existing overhead power lines using some kind of tapes, and optical cables incorporated into the ground wires of overhead lines).

Common name for self-supporting, wrap-on and lashed cables that is sometimes used is “retrofitted cables” because these solutions are applied on existing O/H lines, hence, these cables are added afterwards.

Each option has its advantages and disadvantages in comparison with other ones, both from technical and economic point of view. It is necessary to note that single mode optical fibers are now predominantly used because of larger transmission capacity and lower attenuation than multimode fibers. In the optical cable construction, as the best way to protect the fiber mechanically and to give the fiber enough space for free moving, the loose buffer technique is favored over the tight buffer one.

a) Underground FO cables

In the case of direct burial of the cable, installation works are comprehensive because they include trench excavation and backfilling for cable and joint closures, mechanical drilling and excavation of obstacles at crossings of roads and water-ways. According some experience, total cost of link implemented by underground fiber optic cable is 2.5 times higher in comparison with cost of FO cable itself. Furthermore, the way leave problem has to be overcome, especially in urban areas.

These problems are partially mitigated in case of pilot cables that are laid along power cables in the same trench – each cable “participate” in total cost of installation works with approx. 50% and generally the cost is reduced significantly.

Recently there is an increasing trend of applying new technique of fiber optic cable laying, known as "blow-in": a PVC pipe (40 mm dia), is first buried in the ground and then a fiber optic cable is "blown-in" using special machines which work on the compression principle. The advantage of this technique is that optical fibers are exposed to considerable smaller tightness than in pulling technique of installation. Cable rejects are smaller as the cable ends are not subject to mechanical damages during the process of laying. Finally, metal-free optical fiber cable is protected against mechanical damages.

b) Self-supporting FO cables

Self-supporting cable is suspended between towers, below conductors. This cable should contain a high proportion of a metallic strength member to achieve the necessary strength of the cable. This would, however, significantly increase the load on towers both directly and when combined with wind load. On the other hand, metal-free self-supporting cable has several mechanical behavior problems such as:

- Vibration intensity - the mechanical self-damping of this cable is much lower then that of stranded conductors and for the same induced energy, the vibration angle is, therefore, much larger than for metallic conductors;
- Behavior under wind - due to small weight of this cable, any wind from the side causes wide deflection angle of the cable. This angle is approximately twice as large as the one of phase conductors;
- Behavior under direct climatic conditions - small weight in comparison to the diameter together with a relatively low elasticity modulus and an elongation under high and low temperature conditions. This means that the cable must be put under a high tension and have small sag under normal conditions to avoid small clearance under temperature loading conditions.

Furthermore, application of self-supporting metal-free cable is limited to lines with an operation voltage not exceeding 132 kV due to the problem of degradation of sheathing compound of the cable if exposed to electric fields near the dead end.

c) Wrap-on FO cables

Attaching an optical cable to the existing conductor (wrap-on cable) is a quick way how to install fibre cables on an overhead line but the cable is exposed to the wind and ice loadings (in climate conditions where applicable). In addition, this cable would be vulnerable to damage from lightning and flashovers. As a temporary connection between the existing sections of the network, this solution is quick for installation but should be replaced with a more reliable system at the earliest opportunity.

d) Lashed FO cables

This solution has been appeared recently, as an alternative to wrap-on cables. The only difference is that, instead of the cable, fixing tape is wrapped. All other comments, given under c) are valid also in this case.

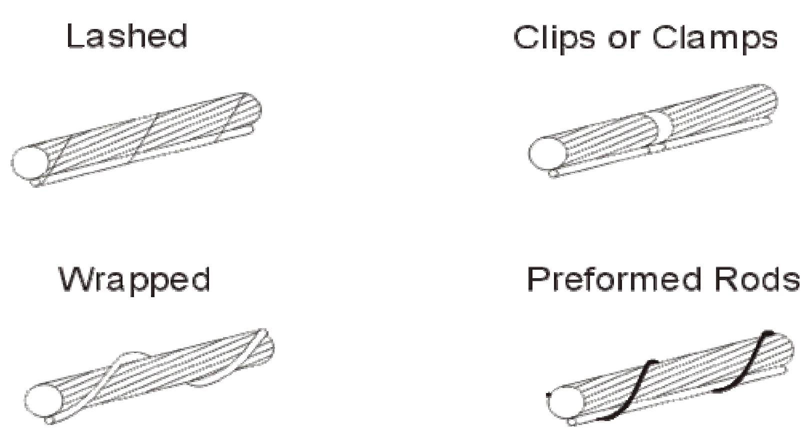


Figure 1: Wrapped-on and Lashed cables – different options

e) OPGW cables

The last solution is to locate the optical cable within a conductor or ground wire. This is the overwhelming balance of advantages as the majority of the mentioned difficulties are eliminated. The advantages of ground wire with incorporated optical cable are as follows:

- The fibers are very well protected by metal of the conductor;
- The system is extremely reliable, especially in climate conditions without snow and ice, as in GCC countries;
- No additional loading is exerted on the towers;
- Installation is straightforward as, apart from jointing the fibers, this earth wire can be treated as a conventional conductor, and
- Normal tension stringing methods are used.

Within ground wire, instead of one core, metal pipe is incorporated, consisting of a certain number of fibers and filled-in with filling compound (jelly). Nowadays, it is standard solution to incorporate 24 or 48 fibers into this pipe that enables not only to meet all requirements of power electric system but also other users in the subject area. Factory lengths of OPGW enable the distance between FO splices to be 2-4 km. Along the way leave, the FO closures are installed usually at the height of 3 m, at the ends of the link, usually are installed at the height of 1.5 m at terminal towers or gantries.

The OPGW solution is especially applicable in case of new O/H lines. Most electric power industries in the world have, as a general rule, apply OPGW at O/H voltage levels 400 kV and 220 KV. For existing lines, OPGW solution is applicable only if ground wire is necessary to be replaced because of its obsoleteness or inadequate cross section.

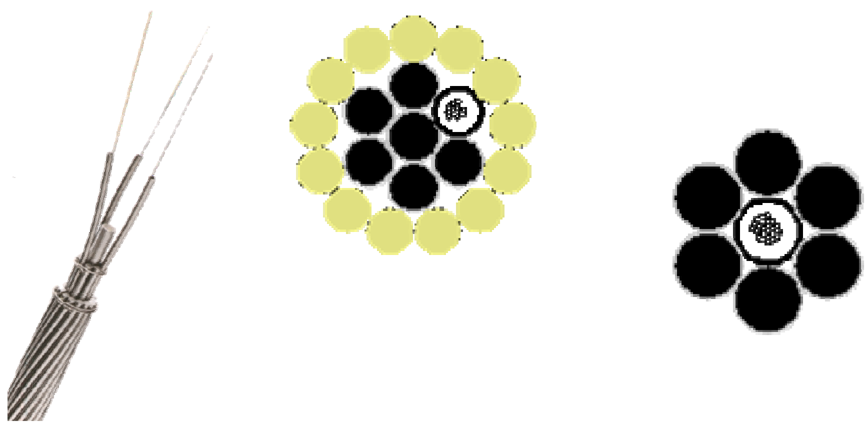


Figure 2: OPGW cables – general view and options of cross-section

3. ECONOMIC COMPARISON OF FO CABLE OPTIONS

Process of planning of telecommunication systems between substations should take into account not only technical but also economic parameters relevant to choice of optimal solution. Results of economic comparison of different options are strongly dependent on particular case, especially country in which the system will be implemented and moment in which elements for this analysis are collected. In addition, this analysis should be based on a large number of assumptions to enable equality of options and to define clearly what is included or not and in which way.

Because of that, we decided to give some kind of summary of analysis carried out for large number of systems and to emphasize several key elements which can be used for rough insight when it is necessary to estimate some solutions in short time.

Following options are compared:

1) Underground FO cables
   - Communication cable
   - Pilot cable
2) Aerial FO cables
   - Self-supporting FO cables
   - Wrap-on/Lashed cable
   - OPGW - Total
   - OPGW - Participation of optics

It is assumed that a FO link includes:

- Fiber optic cable (metal free with 48 single mode fibers and loose type secondary coating);
- Fittings and accessories;
- Fiber joints (closures);
- Approach cable to overhead line hood closure, and
- Terminal line equipment.

The cost of these links includes secondary order multiplex equipment and primary multiplex fully equipped with different kinds of channel units.

The following should be noted:

- The prices include cost for equipment, installation and commissioning, civil works (if any) and other costs (freight and insurance, the customs);
- All prices given are only for budget estimates;
- Expenses for OPGW are given in the form of two estimates: participation of optics in the total expenses and the total expenses for optical ground wire cable to estimate ground wire replacement possibility;
- Installation costs are estimated according to common practice and experience of several contractors because of the fact that these costs depend on so many factors. It is assumed that underground cable is laid in PVC pipes with diameter approx. 40 mm using "blow-in" technique;
- In the case of underground cables, civil works are included (trenching, laying, sand tile, warning tape, backfilling) with total amount for Fiber communication cables and with 50% of the total amount for Fiber Pilot Cables, because they are laid in the same trench as power cables.
- Joint closures are used every 2 km in the case of underground cable and every 3 km in other cases in accordance with standard factory lengths), and
- Approach cables between the terminal hood closure on the mast of an overhead line and substation building with terminal equipment are also metal free optical cable laid in the ground with approximate lengths of 150 m at each substation.

Complying with these assumptions, the overall cost is analyzed as a function of distance.

According to the results of the technical and economic considerations the following conclusions can be made:

- For a new overhead (O/H) line or replacement of the ground wire of the existing O/H line because of inadequate cross-section, the favorable solution would be ground wire with incorporated optical cable;

- For an existing O/H line where the ground wire replacement would be too expensive, self-supporting optical cable provides the best alternative in spite of the fact that the cost of self-supporting cable is greater in comparison to the cost of wrap-on cable;

- For the distances longer than 3 km ground wire solution - participation of optics - is more economical than underground cable, and

- Cost of self-supporting cable is always higher in comparison with wrap-on cable. In spite of this fact, self-supporting cables have several technical advantages and that is why they are wider applied than wrap-on cables.

4. EXAMPLES OF APPLICATION OF DIFFERENT FO OPTIONS

According to previous considerations, in this section are several examples of systems are given in which different FO cable solutions are applied.

4.1 Qatar electric power communication system, Phase IV

The Ministry of Electricity and Water (MEW) in Doha, Qatar, started with the Phase IV of modernization of electric power system in 1991. The system includes all the most significant substations and plants in electric power network: control centers (NCC- National Control Centre and DCC – Distribution Control Centre), substations 220/x and 132/x kV and generation plants. In the process of planning, aforementioned criteria have been taken into account and combined "point-to-point" and "loop oriented" network topology has been applied. Link capacities are 8 Mbit/s. Telecommunication system consists of (Figure 3):

- 14 microwave digital radio links in 13 GHz band, with distances from 3 to 22 km, antenna towers 20 to 40 m and antennas with diameters 0.6 and 1.2 m;
- 9 O/H Lines with optical ground wire (OPGW) cables, total length approx. 670 km;
- 13 optical pilot cable lines, total length approx. 108 km, and
- 5 optical communication cable lines, total length approx. 13 km.

This system is implemented, guarantee period expired and the system is fully in operation.

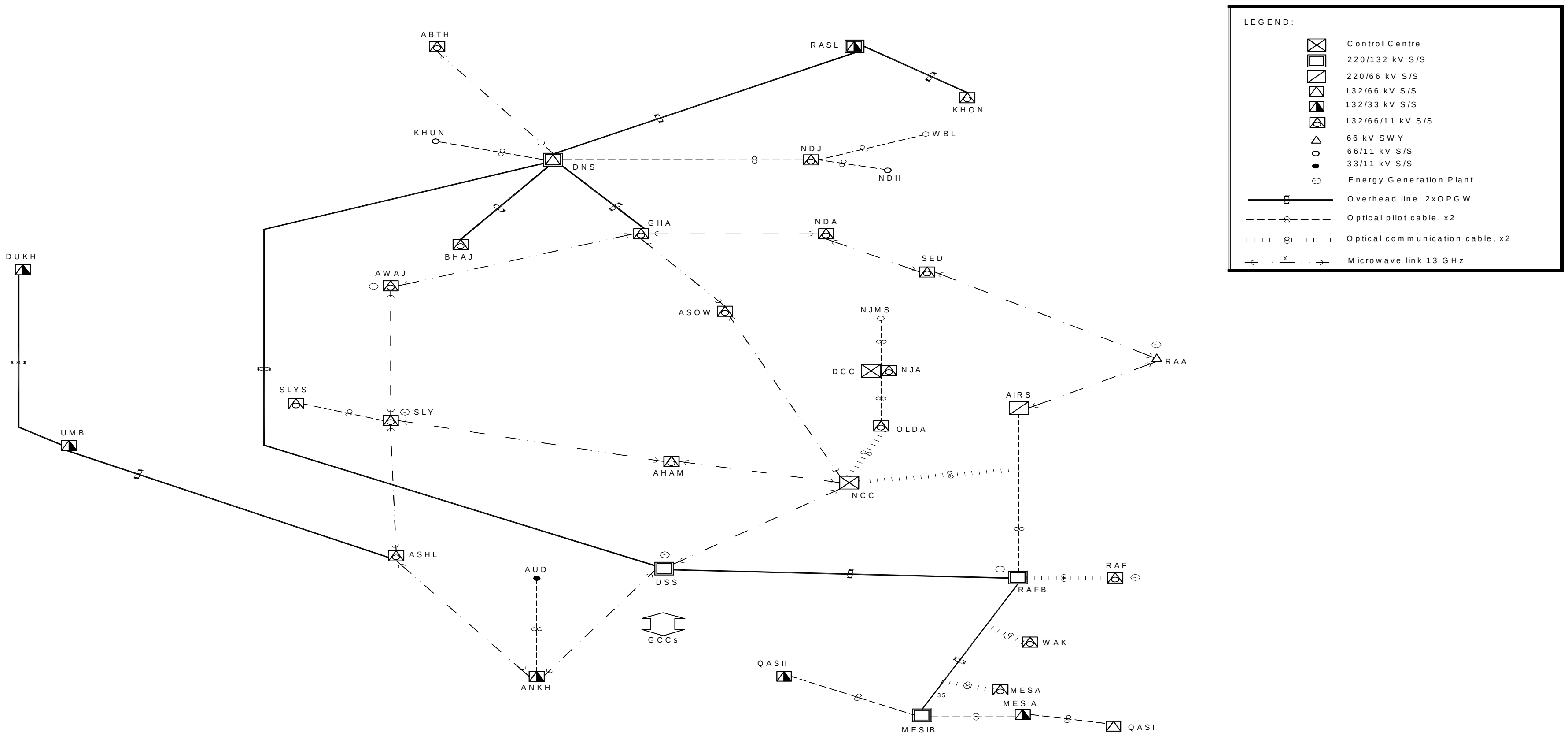


Figure 3: Qatar Electric Power Communication System, Phase IV

4.2 LDC and Communication project, Northern Oman

According to intention of The Government of the Sultanate of Oman to undertake the privatization of the Ministry of the Housing, Electricity, and Water (MHEW), Load Dispatch Center (LDC) and Communication Project started in March 2001. The system includes LDC and 38 primary substations - 5 new substations 132/x kV in Sharquiya region, 4 new substations between existing ones, 1 new substation 220/132 kV, modification of 28 existing substations 132/x kV and generating plants as well as including of 220 kV level into transmission network. The project planned to establish a new modern LDC and associated communication facilities between LDC and the power stations and substations throughout Northern Oman. Link capacities are 8 Mbit/s. Communication system consists of (Figure 4):

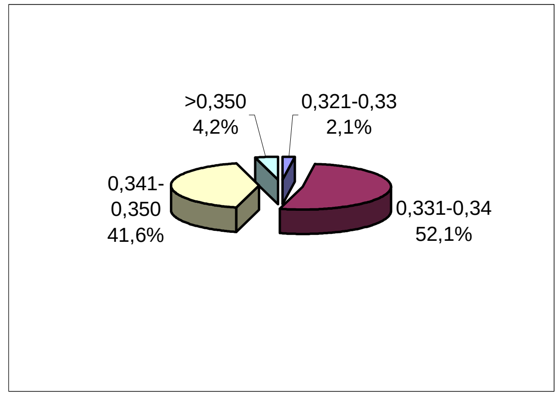
- 16 O/H Lines with optical ground wire (OPGW) cables, total length approx. 890 km;
- 15 O/H lines with retrofitted cables (wrap-on or self-supporting), total length approx. 275 km;
- 1 underground fiber optic communication cable, total length 7 km;
- 7 DPLC links, with capacity 32 kbit/s, and
- 15 PLC links.

This project was finished at the end of 2004.

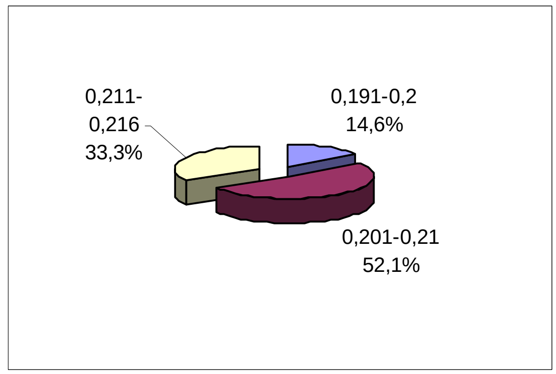
4.3 Typical results of fiber and splice attenuation measurement

During implementation of OPGW links in Qatar and Oman in period 1998 – 2002, fiber and splice attenuation measurements have been made for OPGW of different manufacturers. Typical results of fiber attenuation are presented at figure 5 for installed OPGW, 1300 nm and 1550 nm (5a and 5b, respectively) as well as splice attenuation (5c). From these measurement results it is clear that the results are within expected value intervals, i.e:

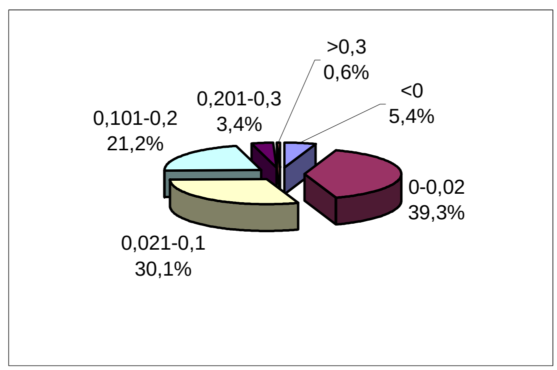
- 95,5% values of attenuation at 1330 nm does not exceed design value of 0,35 dB/km;
- No any measuring value of attenuation at 1550 nm exceeding 0,22 dB/km (design value is 0,25 dB/km i.e there is additional attenuation reserve 0,03 dB/km);
- 74,8% values of splice attenuation does not exceed typical design value of 0,1 dB per splice.



5a: OPGW Fiber attenuation, 1300 nm



5b: OPGW Fiber attenuation, 1550 nm



5c: OPGW splice attenuation

These results, measured in typical Gulf region conditions (high temperature and humidity) enable designers to correct parameters in transmission quality calculation, in segment of optical power balance.

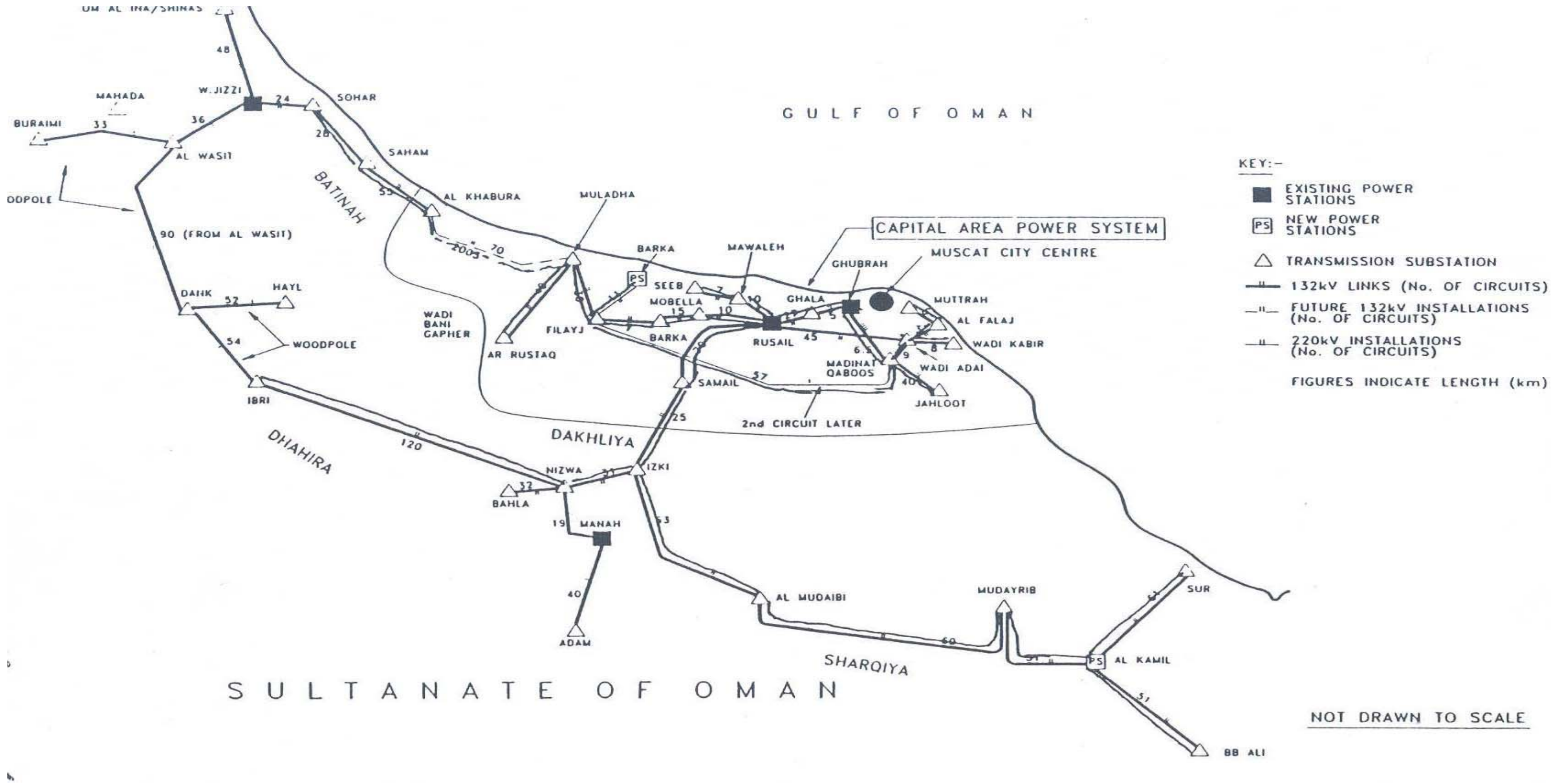


Figure 4: LDC and communication system, Northern Oman

4.4 Impact of environmental conditions to OPGW

Impact of environmental conditions to exploitation of optical ground wire cable (OPGW) implemented in the area with specific climate conditions should be very important. In Gulf region, marine atmosphere, high temperature (mean value around 50 °C), sand wind and industrial zones can have negative impact to OPGW. Illustration of such a case is given at figures 6 to 9.

The OPGW link in the example is implemented by the OPGW whose construction (Figure 6) consists of aluminium slotted core placed inside the aluminium tube and ACS steel wires around the tube.

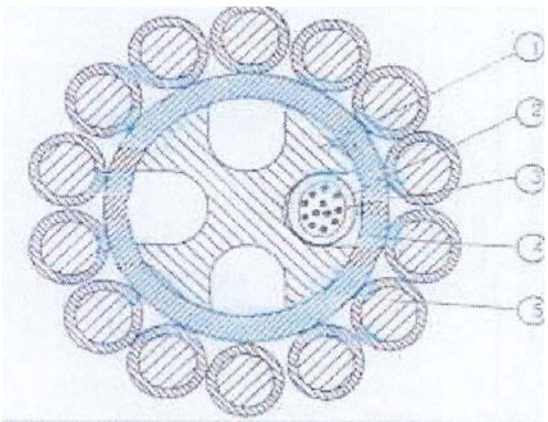


Figure 6: Schematic view of the OPGW wire

The corrosion was observed on area where the aluminium cladding of ACS wire had been removed by lightning, Figures 7 and 8.

Figure 7: Zone of OPGW damaged by lightning

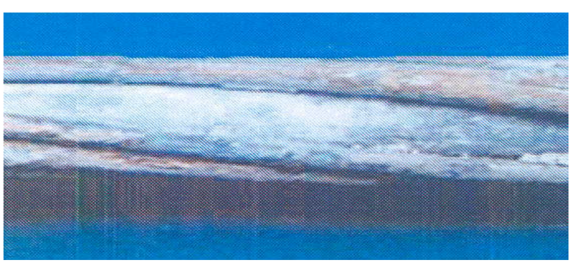


Figure 8: View of the tube after partial removal of ACS steel wires

From the Figure 8, a white powder can be seen on the surface of the aluminium tube when ACS steel wires were removed. Detailed analysis showed that the aluminium tube was corroded and locally cracked, the inside is filled with corrosion products (aluminium hydroxide), the aluminium tube is deformed (Figure 9) and caused pressure to optical fibers that were deformed, too, and connection was lost.

Figure 9: Cross section of the OPGW

Main idea of the authors was to show that OPGW design and implementation process is very complex, because some unexpected problems could arise in exploitation circumstances that are very difficult to recognize in phase of solution creation. Choice of materials as well as OPGW construction should be studied from the very beginning of the design process, taking into account local environmental conditions and taking all necessary measures to eliminate of at least mitigate potential problems. In spite of the problem described, OPGW are and will be preferable solution for electric power communication systems.

5. CONCLUSION

In this paper, some advantages and disadvantages of application of different Fiber Optic cable solutions between substations are summarized. Technical and economic parameters important in process of planning of these systems are considered and several examples are given, based on experience in design and implementation of electric power communication systems in Qatar and Oman, including some measurement results and the example of negative environmental impact. It can be concluded that FO solutions plays very important role in development of electric power communication systems not only in satisfying present needs but in development of new ones.

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